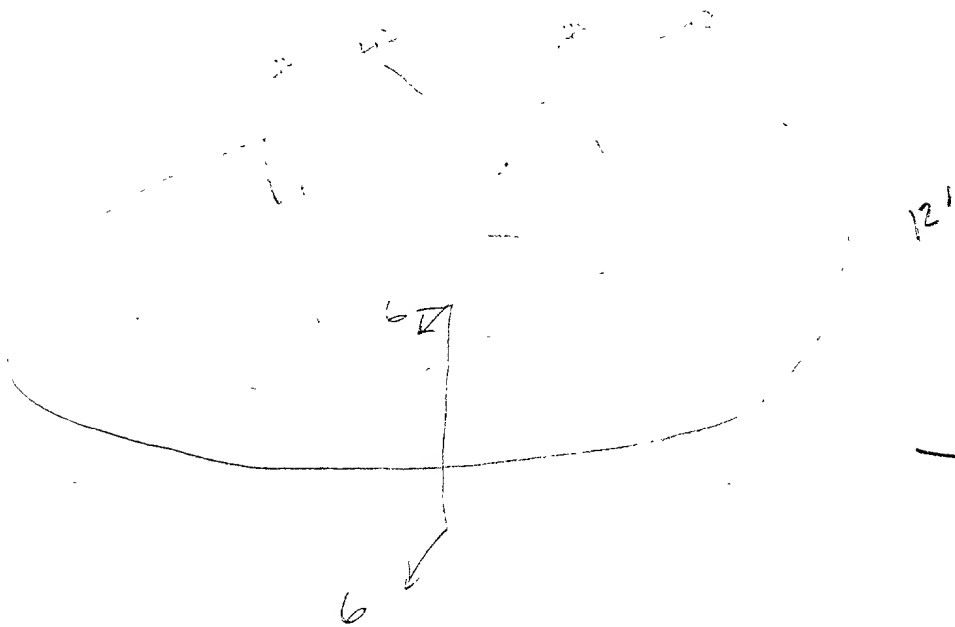
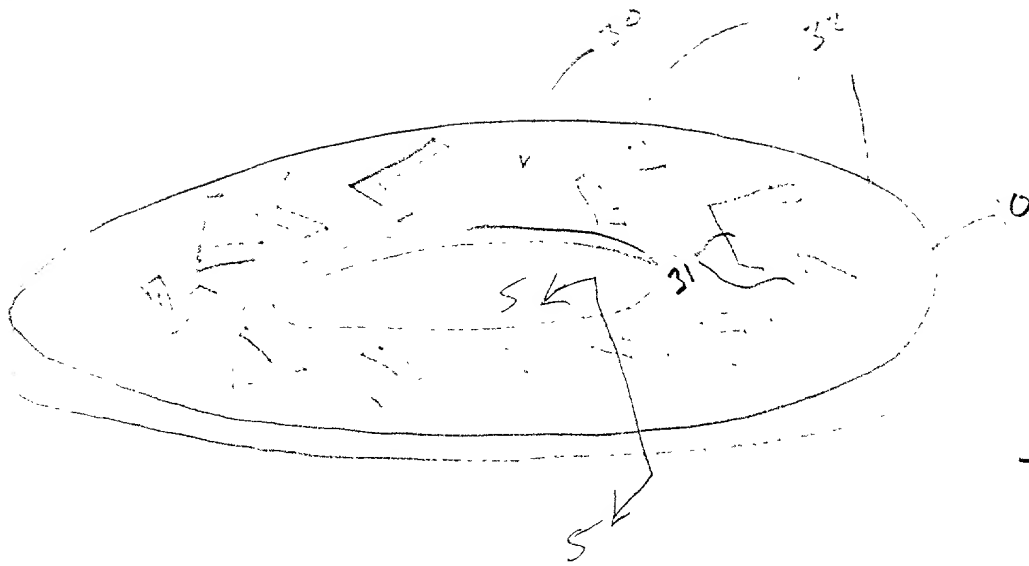


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Fig. 1

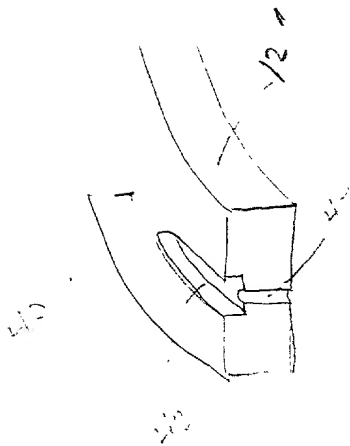
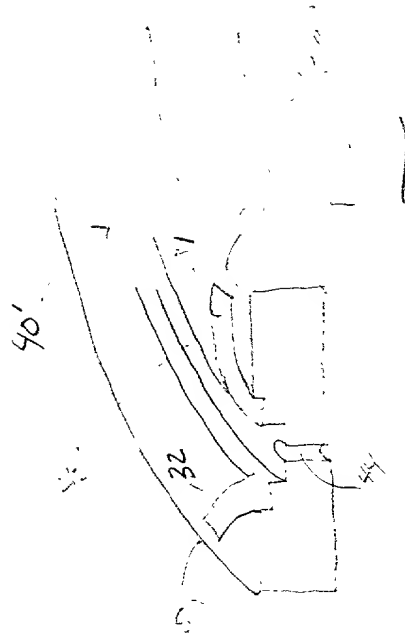


Fig. 2



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Title: Retractable adaptive divert-groove film-riding face seal

Inventor(s): Xiaoqing Zheng

explained later. Normally, the deep feeding groove is not segmented as shown in Figure 2 for manufacturing reasons.

Preferably, seal face patterns shown in Figure 1 or 2 are on the face of stator ring 200. But they can be a combination of the imprints on rotor and stator faces 200,201. For example, the feeding groove 104 and hole 105 can be on the stator ring 100 while the groove 101,106 and dam sections 102,107 are on rotor ring 201. In such case, the two hydrodynamic sections (groove section) 101,106 can extend and meet at the center. Please note that the number of pairs of groove and land can be different for inner and outer seal sections 109,110 in the non-segmented design. However for ease of plotting, same numbers of groove-land pairs are used in all the figures in this disclosure. In addition, the pumping grooves 101,106 are normally 200-900 micro inches in depth; they are shown exaggerated in some plots to better demonstrate the seal configurations.

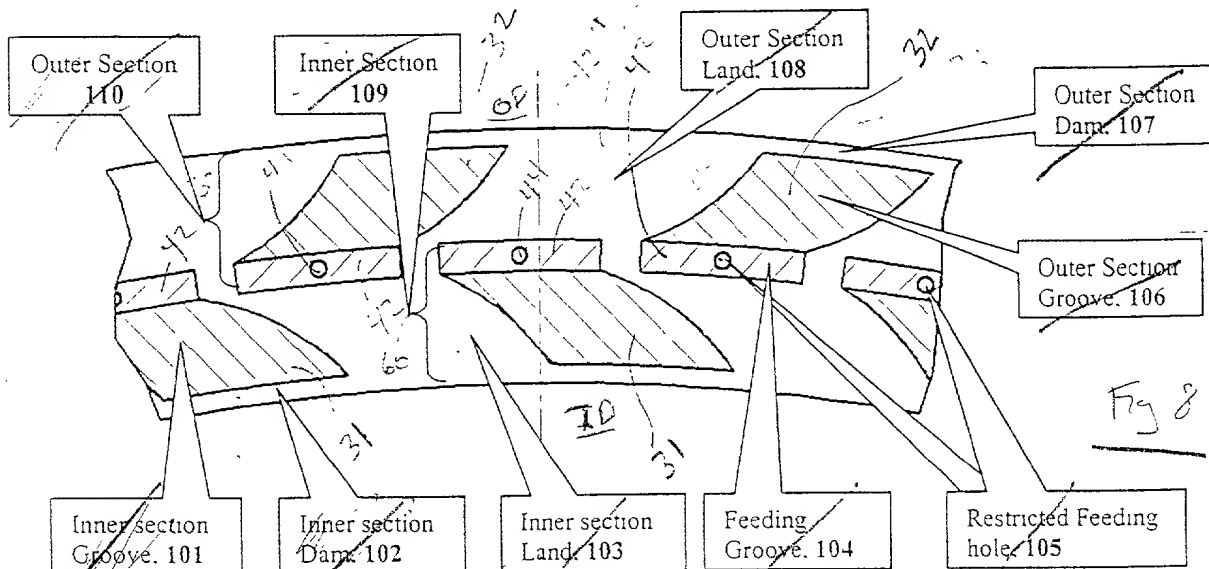


Figure 1. Typical seal face layout for segmented feeding grooves

As mentioned before, a very interesting implementation of the above described idea is to put divert grooves 101,106 on the rotor sealing face 203 but have feeding holes and deep feeding groove on the stator sealing face 202. This is quite natural if the rotor is made of hard material. The deep feeding groove can be round 131 or rectangular 132 at the bottom. Alternatively, we can put feeding hole 105 and deep feeding groove 104 on rotor face 201, but leave pumping grooves 101,106 on stator as shown below. The

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Inventor(s): Xiaoqing Zheng

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feeding holes 105 are aligned in an angle with the rotating axis against the rotational direction. In this way, the rotation effect makes the feeding more effective. The configuration is shown in Figure 3. But for high-speed rotor, the feeding hole 105 may create serious stress concentration. Therefore the first arrangement is preferred.

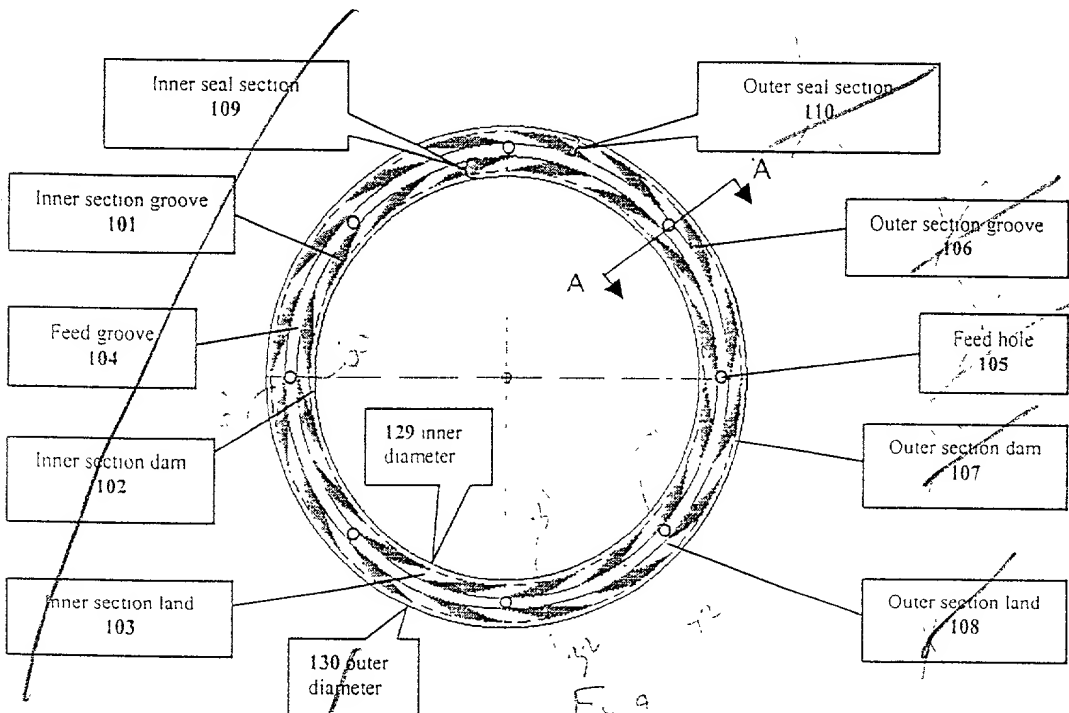


Figure 2. Non-Segmented Divert Groove Face Seal

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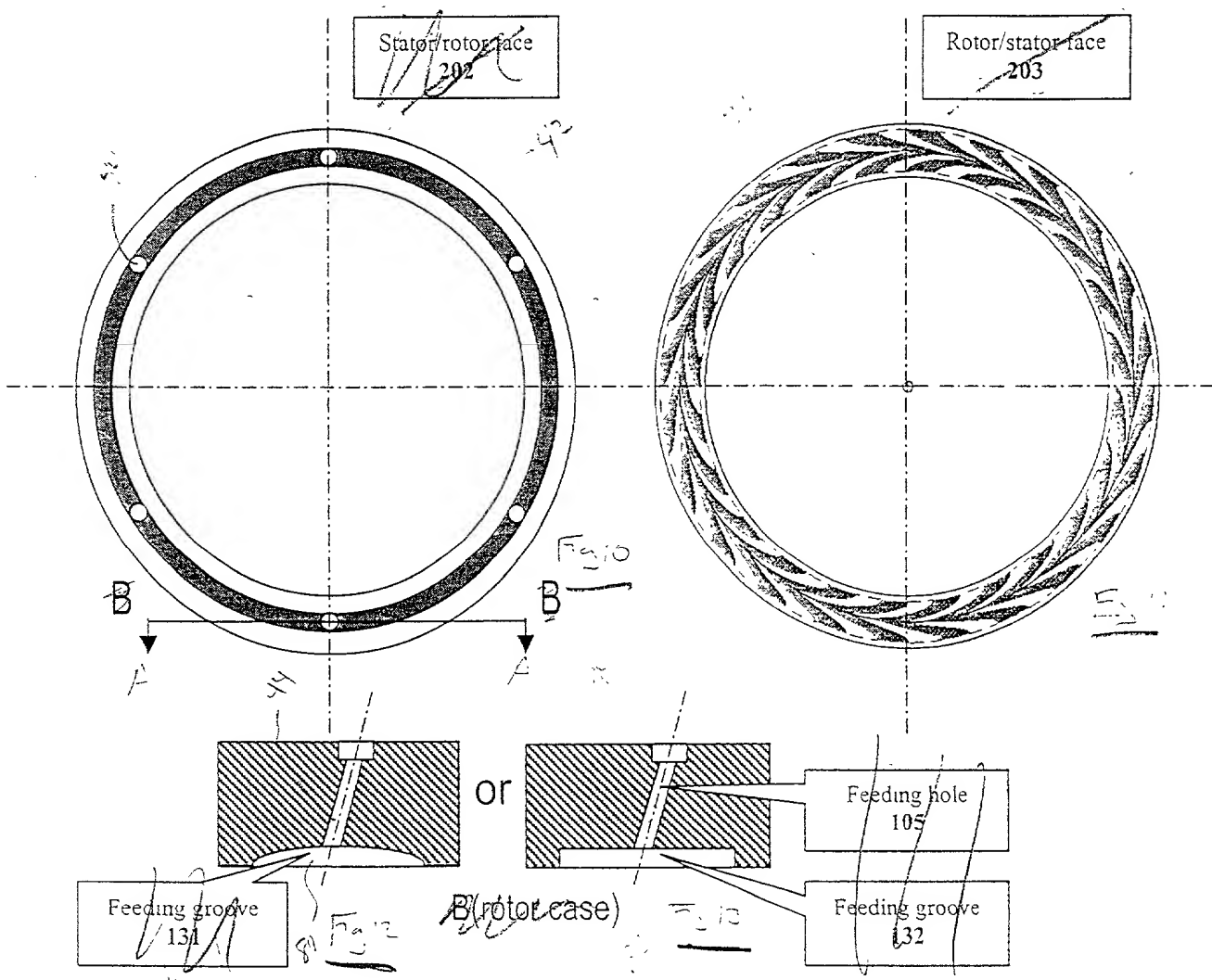


Figure 3: Divert double-groove seal

For the convenience of demonstration, in all the figures shown hereafter, we assume all the features are put on the stator ring 100.

Figure 4 shows a cut side view of the stator. The stator ring 100 is mounted to a stator holder 121 and supported by a bump 123 on the back. The bump is also called back seat 123. Its main function is to provide additional closing force and serves as a support point for the stator ring 100 to rock on. Retracting spring 122 holds the stator back if the pressure difference across the seal is small. This feature is used to

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Title: Retractable adaptive divert-groove film-riding face seal

Inventor(s): Xiaoqing Zheng

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## Key elements of the invention:

A unique feature of the new face seal is that it pumps fluid from inside to edges. This allows the seal to work at tough conditions of severe face deflection. Since the fluid enters from the center, face coning will never cut off fluid from getting into the seal face. The groove profiles are designed to have desirable pumping effects and film stiffness. Even though we still call it double-spiral groove seal, the groove shape does not necessarily have to be a spiral. As a matter of fact, the spiral curves are usually approximated by circular arcs for the ease of manufacture. Furthermore, this invention suggests use of groove profile curving forward 119 instead of conventional curving backward in cases that stronger pumping effects are needed. The alternative groove profiles are shown below.

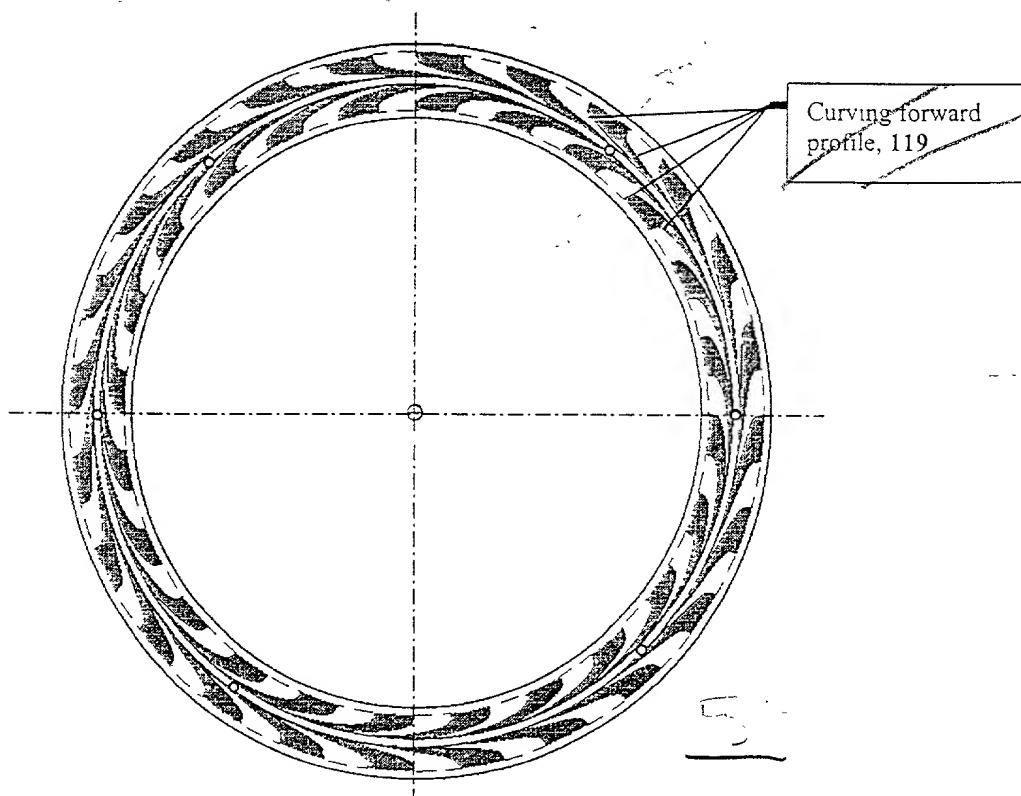


Figure 5: An alternative groove profile

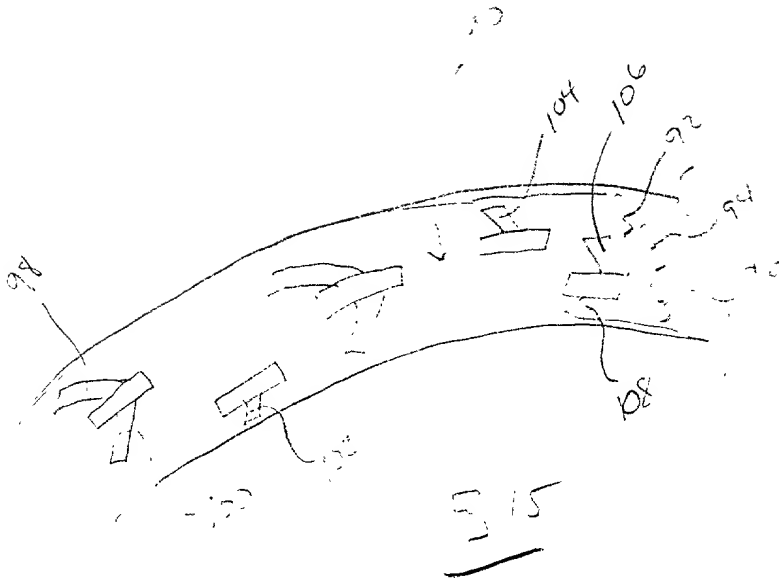
In order to make the stator ring 100 adaptive to rotor face 201, the stator ring is designed to be flexible in terms of coning deflection. Therefore the thickness of the stator ring is chosen to be as small as the manufacturing process can allow maintaining flatness of the seal face. The flexibility of the stator ring combined with the restoration capability of the seal face makes the seal highly adaptive to the rotor ring face 201. The mechanism is explained in the following.

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Inventor(s): Xiaoping Zheng

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Before we go on to discuss the stator responses to rotor deflection, let us define the sign of coning deflection first. Following the face seal convention, if the coning causes a divergent gap 128 from outer diameter 129 to inner diameter 130, we define the coning as negative. If the coning by either stator or rotor causes a convergent seal gap 128 between the stator and rotor sealing faces 200, 201, the coning is defined as positive.

Figure 6 shows a typical pressure distribution 150 on the seal face at a design operation condition. The rotor sealing face 201 and the stator sealing face 200 are in a parallel orientation. The total forces 151 from the outer seal section, feeding groove and inner section and their equivalent acting positions are illustrated with vectors. The stator ring experiences a net moment of zero.

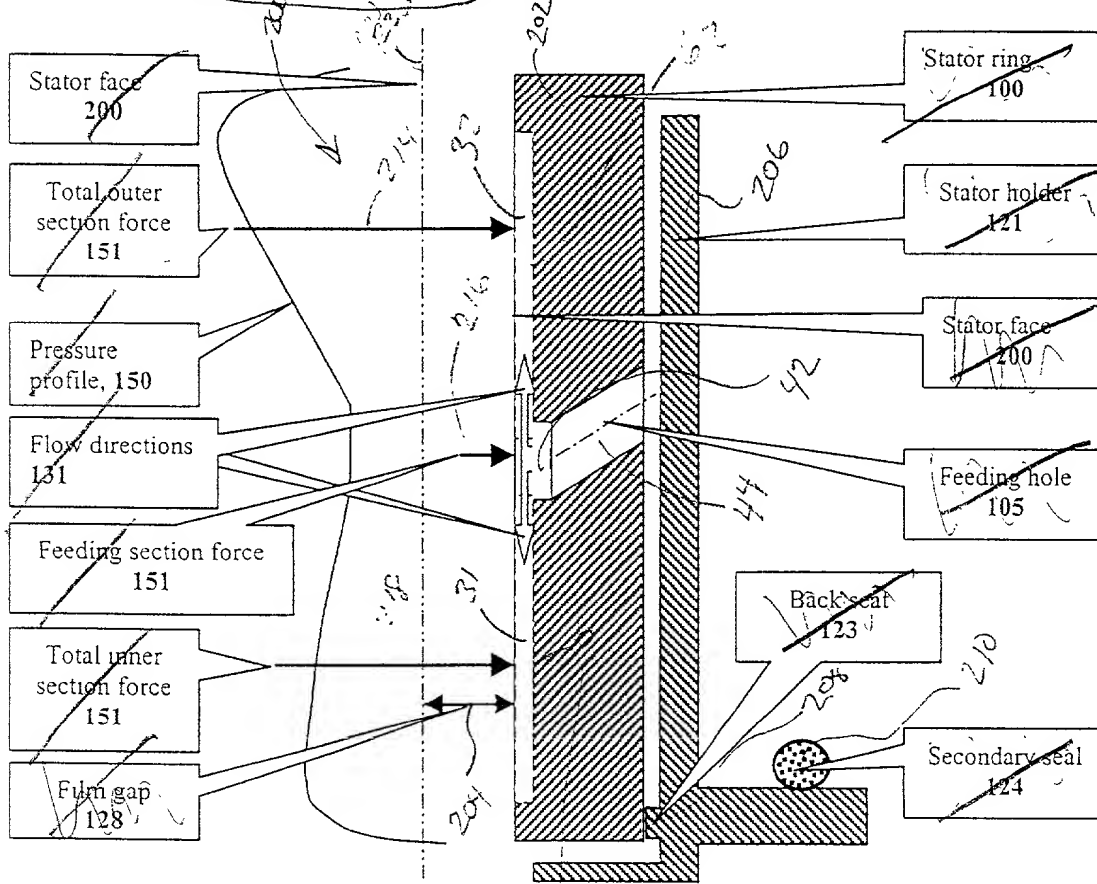


Figure 6. Design condition without rotor deflection

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Title: Retractable adaptive diver~~g~~-groove film-riding face seal

Inventor(s): Xiaoqing Zheng

When the rotor face 201, deflections cause negative coning, the outer seal section 110 is working in a convergent film (refer to the flow direction 131). That makes the groove 106 work more effectively to create higher pressure in the hydrodynamic section. Therefore, the outer seal section 130 generates more positive moment to open up the clearance at outer diameter 130. Meanwhile, the inner seal section 109 is working at a divergent film. That reduces the hydrodynamic effects of the grooves 101. Less pressure, and therefore less negative moment, is generated by the inner seal section 109. The net increase of positive moment causes the stator ring 100 to cone positively and form a uniform film thickness as shown in Figure 7.

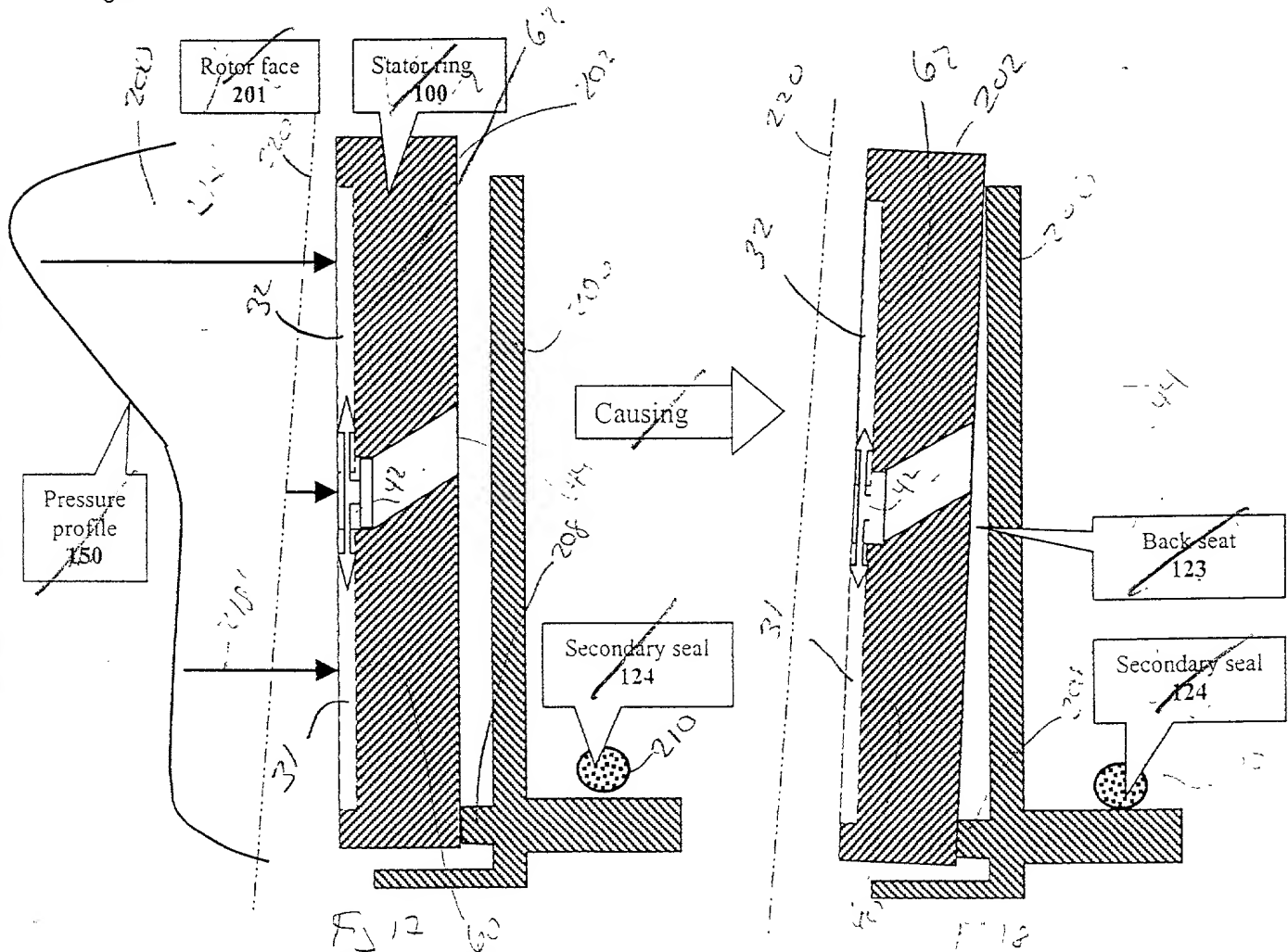
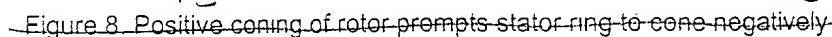




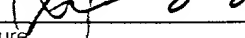
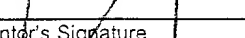
Figure-7: Negative coning of rotor prompts stator ring to cone positively

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Inventor(s): Xiaoqing Zheng

When the rotor face **201** deflections cause positive coning effect, the outer seal section **110** is working in a divergent film. That makes the groove **106** work less effectively to create high-pressure zone in the hydrodynamic section. Therefore, the outer seal section **110** generates less positive moment. Meanwhile, the inner seal section **109** is working at a convergent film. That increases the hydrodynamic effects of the grooves **101**. Larger pressure, and therefore larger negative moment, is generated by the inner seal section **109** to open up the clearance at inner diameter **129**. The net increase of negative moment causes the stator ring **100** to cone negatively and form a uniform film thickness as shown in Figure 8.



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prevent seal faces from touching and rubbing during engine start-up and shut-down. A typical stator is shown below. Please note that the top does not necessarily correspond to outer diameter 130, it rather corresponds to wherever the system pressure is.

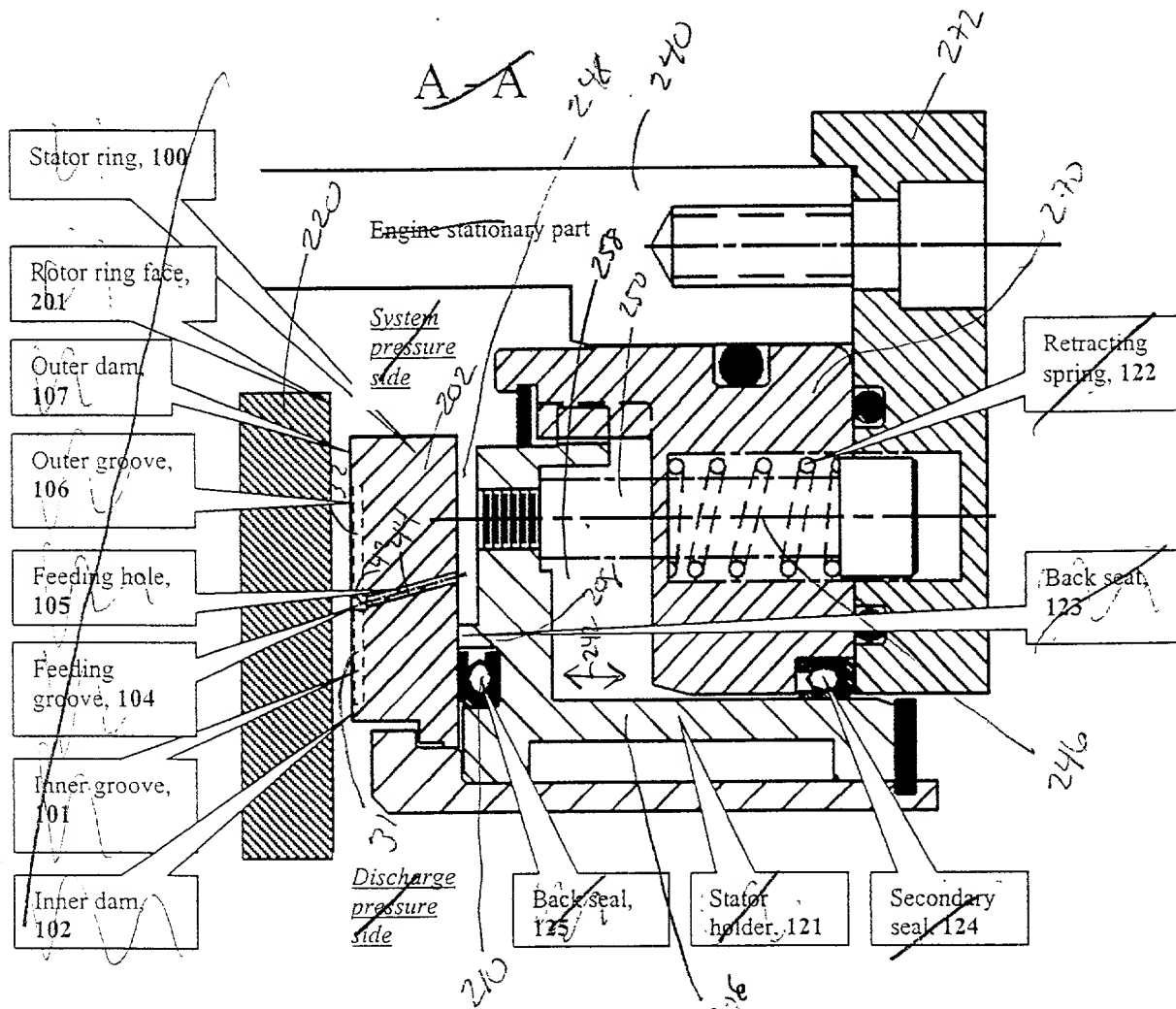


Figure 4. Seal cross section

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